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CARTOGRAPHIC REPRESENTATION OF GEOLOGICAL FORMATIONS.

As CARTOGRAPHIC units, in the representation of geological structure, the lithologic individual, the faunal stage and the geological formation are commonly regarded as practically identical. In reality, they are fundamentally distinct from one another. Moreover, these are not the only units which it is possible and practicable to map and bring out clearly the geological structure of the area investigated.

In the recent discussions on the units of geological mapping, one of the most important fundamental factors appears to be entirely overlooked. The two leading phases of the subject are admirably summed up in the recent articles of Messrs. Willis[1] and Cross.[2] Although, at first glance, these authors seem to present radically different views, they are not, actually, so far apart in their contentions as they would have us believe. Mr. Cross' conception is the more philosophical of the two; it is based on genetic grounds; and it is the one which must finally prevail, though the local criteria of discrimination may be diverse in different cases. In actual practice, Mr. Willis' expressed idea has the greater force and must be the one which must necessarily long be followed. But the two conceptions are not incompatible. In the practical application of the principles, the final results become very nearly identical.

To every one who has given the subject critical attention, it

[1] JOUR. GEOL., Vol. IX, p. 557, 1901. [2] *Ibid.*, Vol. X, p. 223, 1902.

must be quite evident that no standard yet proposed for the delimitation of geological units in cartographic representation exactly expresses the essential features of a complete and rational scheme. As in all classifications of natural objects, that of geological units, formations, or terranes should be in its highest type genetic in character. Moreover, it should be strictly stratigraphic, depositional or sequential, using these terms in their broadest sense to include all rock-masses, igneous, metamorphic and sedimentary. With this understanding of the theme, the most obvious characteristic of a stratigraphic scheme is not the terranes or rock-masses themselves, nor any of their contents, but their geometric elements, their bounding or stratigraphic planes. In order not to carry with it the usual narrow idea, some such term as depositional or sequential planes should be used in place of the name stratigraphic, and these titles will be hereafter given preference. The sequential, depositional or sedimentation planes have different taxonomic values according to the general scheme of classification adopted[1].

A cross-section of the cartographic units, or geological formations, as they occur in nature, may be represented by the following sketch:

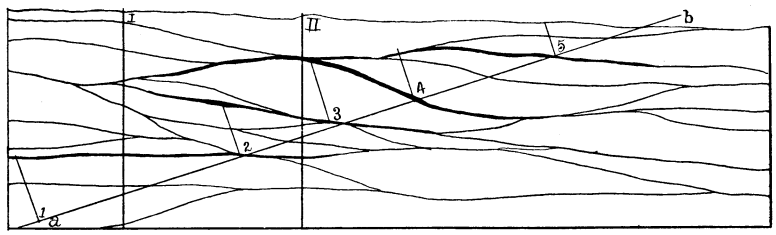

FIG. 1.—Geologic units in cross-section.

In the general, abstract or ideal instance, each lens-shaped figure is the unit established "with regard to all the facts and conditions of the case, and not upon the restricted basis of any part of those facts. It represents as much of the geological development of the earth recorded in the area covered as is practicable." The net-work of formations coincides with the

[1] *American Geologist*, Vol. XXIV, p. 294, 1899.

lines and planes of sedimentation, or natural sequence, to use a more comprehensive term. It gives a foundation for determining geologic structures and deciphering geologic events. This foundation is the same as that governing sedimentation and the sequential arrangement of rock-masses. The scheme is, therefore, genetic. It is of secondary importance to consider the composition and contents of the various lens-shaped figures. In some cases most value must be placed upon the lithologic character of a terrane. In other instances, the contained fossils, or minerals, are the determining factors. Under certain conditions still different features must be taken into consideration. The cardinal fact to be always recognized is that the cartographic unit, the geologic formation, is essentially an abstract conception. It may also be a lithologic, or faunal, or mineralogic, or physiographic, or some other kind of unit capable of being represented on maps.

As a matter of fact the lithologic features, the faunal characters, the mineralogic contents, as well as many other criteria of discrimination, are so grouped genetically to the depositional units which it is desired to represent on the map, that if the decipherable record of each were perfect, a cartographic representation of the one set of facts would in a general way indicate the probable outline of each of the other sets. But the fact that the records of all of these groups of data for the determination of the geologic formations are at best comparatively so meager, makes it incumbent upon the geologist to delimit his cartographic units at first according to the most obvious features presented in the several areas covered.

It so happens that in the field the most obvious and most useful single feature in recognizing and tracing a geological formation is the lithologic. Checked by other criteria, then, the lithologic unit corresponds very closely to the ideal cartographic unit established. For all practical purposes for which the geologic map is constructed lithologic individuals are amply sufficient and accurate. When more refined investigation is taken up some slight changes in the lines of formational delimitation may be necessary; but if the lithologic determinations

have been made with ordinary care it will probably be rare that radical alteration will be demanded.

In the present stage of geologic inquiry it is neither practicable nor desirable to map all districts with uniform refinement. Among geological formations, we shall no doubt eventually establish and indicate on all geological maps about five degrees of taxonomic rank. The division lines in any one area can only be fixed after very careful comparisons with those of all the neighboring districts. In the main, these terranal lines will be found to correspond to, or can easily be adjusted to, the divisional lines separating the lithologic individuals ordinarily recognized.

When the lithologic features of formations gradually merge into those of others, or when there is a rapid alternation of different kinds of rock layers, fossils or minerals, other criteria may have to be resorted to in order to properly delimit the terranes. But this fact certainly in no way invalidates the general principles involved in the recognition of the lithologic individual as the leading object to be represented in cartography.

When, for example, it was found upon detailed faunal examination[1] that the great St. Clair limestone of Arkansas, which had long been considered by the workers of that state as a single lithologic unit, was in reality two great limestones of almost identical lithologic appearance, the one Ordovician in age, and the other Silurian, it did not render worthless the maps upon which these two terranes had been represented as a single cartographic unit. Nor is the principle of mapping the lithologic individual to be given up on this account. Early observation was merely insufficient.

In the case of the ferruginous sandstone of southeastern Missouri and southwestern Illinois there is not a single continuous stratum, but a large number of disconnected deposits, lithologically indistinguishable, and lying, at least, at two very different geologic horizons. One horizon is below the Kaskaskia limestone and the other above that great rock-mass. The one is early Carboniferous; the other mid-Carboniferous. The lower continuous terrane is known as the Aux Vases sandstone; the

[1] *Am. Jour. Sci.* (3), Vol. XLVIII, p. 327, 1894.

other is formed by the basal sandstones of the Coal-measures. Farther southward, in Arkansas, the difference in the stratigraphic horizons of the two is upwards of 20,000 feet. Yet, because of peculiarities of position, the existence of an intervening unconformity plane, and the nearly same level above the sea of neighboring outcrops, of the two horizons on the Mississippi river, Worthen[1] and others were led to erroneously ascribe to the Kaskaskia (Lower Carboniferous) an extensive flora of the Coal-measures.

A different example is that of the Carboniferous of Arkansas. There is the enormous thickness of 26,000 feet of sediments. Sedimentation has been uninterrupted throughout the entire sequence. In the last formed terrane of the Lower Carboniferous, there begins an alternation of sandstones and shales, with some coal seams, continuing to the top of the section. About 24,000 feet of this section may be regarded as a lithological individual quite "uniformly varied in character." Data obtained farther north in Missouri show that 23,000 feet of this enormous section are unrepresented. The Arkansas section belongs to at least three great terranes, each having a taxonomic rank of series. Measured in feet, the median one alone is five times as great as all the rest of the Carboniferous represented in the Continental Interior. The conditions presented are represented below. Viewed from Arkansas alone the lines separating the distinct geological formations might forever remain unnoticed in the great lithologic individual. It is only by a comparison with sections in other localities that the terranal divisional lines may be properly drawn.

FIG. 2.—Carboniferous Sedimentation in Mississippi Valley.

There seems to be only one answer to the question: "What should a geological map represent?" That is Mr. Cross' observation that "it should represent as much of the geologic development of the earth recorded in the area covered as is practicable."

[1] *Illinois Geol. Surv.*, Vol. I, p. 79, 1866.

In considering every unit that is a possible basis for cartographic representation, a number of conditions have to be fully satisfied, in order that the best results may be obtained. As nearly as possible the unit adopted should be an abstract one, since schemes which have been elaborated, or may be in the future proposed, may not have different factors or different kind of factors to appose when the new facts are compared. The unit should be practically adaptable in order that knowledge once acquired may not have to be worked over anew in the field with each change of ideas necessitated by the constantly increasing use of more and more refined methods. The unit should be elastic, because too great rigidity of plan often breaks down the best of schemes. The unit should be easily recognizable and rapidly delimitable in the field; it should be of such character as to be readily traced from point to point, quickly run in on the map, and easily followed on the ground by subsequent investigators who may use the map.

It has been asserted that the lithologic map is a return to the so-called geological map of a century ago. It does not appear that the facts of the case warrant this statement. The geological map of today based strictly upon lithologic individuals is very nearly as fundamentally distinct from the mineralogical map of a hundred years ago, as is the modern map in which so-called geological formations are depicted. In mapping the geological features of an extensive region, work such as the federal government and some of the state geological surveys are engaged upon, the lithological individual for cartographic representation necessarily takes precedence over all other features. It will be a long time after the geological map based upon lithology principally is ready to be issued, that the perfected map of ideal geological formations can be made. In the majority of cases the delimitation of the latter must always rest very largely on the lithologic characters. A map of units recognizable in the field only after about as much study as was devoted to the terranes in the first place by the expert stratigrapher is of small practical use.

For a long time yet in modern areal work, the lithologic indi-

vidual, delimited if necessary by the aid of other criteria, appears amply comprehensive and exact for all purposes to which the ordinary geological map is put. As an aid in the development of the mineral resources of the country — the primary object of work of this kind — maps in which the lithologic individual is the unit amply suffice. In practice in the field, the units broadly defined by the lithologic characters, and those indicated by the more philosophical geologic formations, are generally near enough alike to enable future investigators to do their work without hindrance or uncertainty.

The suggestion of a faunal map eventually following the lithologic map as an integral part of a complete geologic atlas appears somewhat infelicitous. There is certainly no room whatever for such a dual plan in mapping. Such a scheme merely leads to others, maps based upon every criterion known or which may be devised. This is a proposition for which there is not the slightest demand. It is beyond all probability that parallel subdivisions should ever be found that are based upon radically different criteria. When we consider a dual scheme with a structural phase and a time phase based entirely upon fossils we are considering incongruous things. And there is not necessarily any logical connection.

In Europe, there is a classification generally presented that is dual in character, though with singular nomenclature. Thus, all the subdivisions of terranes and of time are strictly paralleled. The International Geological Congresses have adopted the same plan. It must be quite evident to the practical field geologist that there are very serious objections to this scheme. The critical criteria in the rock-scheme and in the time-scheme are fundamentally distinct. In fact, they have no genetic relationships whatever.

In reality, we have more than a dual scheme of classification in geology. There is a triple scheme, a quadruple scheme, and schemes multiple according to the number of standards involved. Each standard gives rise to a different scheme.

The principle underlying the classification of natural phenomena is that different kinds of criteria give rise to different

taxonomic groups. The arrangement of rock-masses affords no exception to the rule. If the life phases be used as the predominant feature in delimiting the subdivisions of one order, prevailing lithologic character may be given greatest weight in another; physiography or specific biotic aspect in a third. Matters are greatly simplified by regarding the larger subdivisions of the geologic scale as essentially arbitrary, abstract time divisions, in which lithology has no place. With the smaller subdivisions, which are best considered as essentially structural divisions, the time element may be practically neglected.

While we have to allude to the time-interval, during which every rock-mass was formed, we have only universal structural units represented in the major two of the five taxonomic categories usually recognized. On the map, the expression of the time of formation of the terrane is by a distinctive color. The smaller of the universal time-units is thus represented. In like manner, only one of the rock categories becomes important on the map, and this is commonly represented by a standard pattern. This, too, is the smallest unit that is of broad geologic significance. While this plan does not always meet every case, it only needs slight adjustment from time to time in order to make it the most serviceable, the most practical, the most elastic, and most nearly in accord with local facts, of any scheme yet devised.

After all, the cartographic unit, like the species in zoology or botany, is necessarily a matter of convenience. In the exact delimitation of both, there enters very largely an element of personal judgment. Through the consensus of opinion we finally arrive at a tolerably good idea of what each unit should be.

It is commonly recognized that the principal criteria followed in delimiting the several taxonomic orders of units and in geological classification are (1) the relative progress of life in general as compared with that now existing; (2) the prevailing biotic type; (3) the general lithologic phase; (4) the specific lithologic character; and (5) the specific fossil feature.

Reference is here made to our most approved ideal classification because the lithologic individual fits closely into this scheme as the taxonomic subdivision of the fourth order. The

case of the St. Clair limestones of Arkansas, already referred to, and the formations of the Rico mountains, mentioned by Mr. Cross, are good examples in which strict lithologic separation was not obvious at first glance. In reality, Cross and Spencer's "Hermosa," "Rico," and "Dolores" formations approach definite geological formations only approximately. They represent no nearer the real geological formation than do purely lithologic individuals. Exact faunal studies in the Rico and neighboring districts are likely to require the divisional lines to be drawn at quite different horizons. When the fuller geological history of the region shall have been made out further rectification will doubtless be found necessary.

As a matter of fact, the lithologic individual based primarily upon lithology and secondarily upon fossils contained, and the "geological division" based upon the fossil characters have essentially the same kind of values as geological elements. But Mr. Cross, in his delimitations, does not depend entirely upon the faunal features, for he goes on to reënforce his statements by giving other reasons for drawing his lines where he does. Lithologic features are manifestly among the most important criteria in tracing the "formations." In the same way it is quite apparent that the advocates of strictly lithologic individuals in mapping do not and cannot depend wholly upon a uniform rock character.

This phase of the question leads to the statement of a more general one, that the main thing is to give clearer definition, than has usually been done, of each cartographic unit proposed. The unit should be defined according to (1) geographic distribution, (2) topographic expression, (3) lithologic nature, (4) stratigraphic delimitation, (5) biotic definition, and (6) mineral content.

When this shall have been done the foundation will have been laid for the establishment of real Geological Formations expressive of the geological history of the area mapped. The approximate "lithologic" map will not have to be materially changed, but only accompanied by a few words of additional explanation.

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